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DUAL TASK AUTOMATIC AND CONTROLLED PROCESSING IN VISUAL SEARCH:--ETC(U)
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DUAL TASK AUTOMATIC AND CONTROLLED PROCESSING IN VISUAL SEARCH, CAN IT BE DONE WITHOUT COST?

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Walter Schneider and Arthur D. Fisk

REPORT No. 8002

LEVEL II

→ **HUMAN ATTENTION RESEARCH LABORATORY** ←

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This research was sponsored by the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract No. N00014-78-C-0612, Contract Authority Identification No. NR 150-409.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER (14) 8002

2. GOVT ACCESSION NO. AD-A084 143

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle) (6)
Dual task automatic and controlled processing in visual search; can it be done without cost?

5. TYPE OF REPORT & PERIOD COVERED (9)
Technical Report

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s) (10)
Walter Schneider ~~and~~ Arthur D. Fisk

8. CONTRACT OR GRANT NUMBER(s) (15)
N00014-78-C-0012, PHS-MH-31425

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Psychology Department
University of Illinois

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
NR 150-409

11. CONTROLLING OFFICE NAME AND ADDRESS
Personnel and Training Research Programs
Office of Naval Research Code (458)
Arlington, VA 22217

12. REPORT DATE (11) (9)
February 1980

13. NUMBER OF PAGES
44

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
(12) 46

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
This work was also supported in part by NIMH grant number 5 R01 MH 31425.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
attention, dual task, secondary tasks, target detection, visual perception, automatic processing, control processing, overlearning

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The automatic/control processing framework proposes that automatic processing can be done without cost. Experiments utilized a multiple frame procedure in which subjects searched for one target character in a series of 12 rapidly presented frames. The type of processing, controlled or automatic, was manipulated by requiring search for variably mapped (VM), or consistently mapped (CM), target and distractor sets. Subjects participated in either single VM (controlled processing), single CM (automatic processing), or (over)

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S/N 0102-LF-014-6601

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

411 759

20. dual CM/VM search conditions. Small dual task hit rate decrements (less than 5%) occurred if subjects dual processed the same location, larger decrements (greater than 10%) occurred if each process was carried out on a different diagonal. The deficits were shown to be the result of a large criterion shift (beta=69) in the automatic process. Combining joint automatic and control processing with emphasis on the control processing task was shown to cause no sensitivity change in either task and a severe criterion shift in the automatic process. Automatic (CM) processing performance was shown to become less resource demanding with practice. However, control processing (VM) conditions were always sensitive to resource reductions and were influenced by target probability effects. Subjects showed a tendency to waste control process resources when performing an automatic process. The application of these results and the automatic/control processing framework to between and within process dual tasking were discussed.

Dual Task Automatic and Controlled Processing in Visual Search, Can it be done without cost?

Walter Schneider and Arthur D. Fisk

Report 8002

Human Attention Research Laboratory

University of Illinois

February 9, 1980

Running Head: Dual Automatic & Controlled Processing

Abstract

The automatic/control processing framework proposes that automatic processing can be done without cost. Experiments utilized a multiple frame procedure in which subjects searched for one target character in a series of 12 rapidly presented frames. The type of processing, controlled or automatic, was manipulated by requiring search for variably mapped (VM), or consistently mapped (CM), target and distractor sets. Subjects participated in either single VM (controlled processing), single CM (automatic processing), or dual CM/VM search conditions. Small dual task hit rate decrements (less than 5%) occurred if subjects dual processed the same location, larger decrements (greater than 10%) occurred if each process was carried out on a different diagonal. The deficits were shown to be the result of a large criterion shift (beta=69) in the automatic process. Combining joint automatic and control processing with emphasis on the control processing task was shown to cause no sensitivity change in either task and a severe criterion shift in the automatic process. Automatic (CM) processing performance was shown to become less resource demanding with practice. However, control processing (VM) conditions were always sensitive to resource reductions (due to secondary tasks) and were influenced by target probability effects. Subjects showed a tendency to waste control process resources when performing an automatic process. The application of these results and the automatic/control processing framework to between and within process dual tasking were discussed.

Dual Automatic & Controlled Processing

Dual task performance is an important concept in the understanding of human behaviors in complex environments, and the development of skilled performance. Dual task concepts are applicable to two different forms of dual tasking situations. A between process dual task is one in which two unrelated tasks are being processed simultaneously (e.g., driving a car and carrying on a conversation). Within process dual tasking occurs when two tasks are carried on simultaneously to accomplish one specified goal (e.g., in reading the tasks of word encoding and reading comprehension are occurring simultaneously). In both of these tasks within a process, a potentially limited resource is allocated between the component tasks.

Several current theories predict a deterioration in performance in dual task situations. Kahneman (1973) proposed an "undifferentiated resource pool" to explain tradeoffs in dual task situations. Under this model, if two tasks require more than the available resources, performance on one or both of the tasks would deteriorate in comparison to the single task performance. Navon and Gopher (1979) have elaborated this model in greater detail applying the concepts of micro-economic theory to resource tradeoffs. Wickens (1980) has modified a single undifferentiated resource pool hypothesis, proposing that there may be several somewhat differentiated resource pools specialized to particular functions (encoding, transformation, and response).

Frequently, experiments designed to measure dual task effects find no interference between tasks (see Kerr, 1973; Ogden, Levine, and Eisner, 1979; Wickens, 1980). Subjects have been able to perform complex dual tasks with little or no measurable interaction. For example, subjects have been able to read while writing (Downey and Anderson, 1915), read one passage while transcribing dictation (Spelke, Hirst, and Neisser, 1976; Hirst, Spelke, Reaves, Canarack, and Neisser, 1980), shadow verbal messages while playing a piano (Allport, Antonis, and Reynolds, 1972), and fly complex aircraft formation maneuvers while digit cancelling (Colle and De Maio, 1978).

Within process dual tasking frequently shows that resources are allocated to higher levels of processing as practice continues. For example, in the learning of telegraphic skills (Byran and Harter, 1899), receivers initially expend their resources trying to identify letters. With practice, their efforts are shifted to identifying words, then phrases, then whole sentences, and eventually operators spend their resources interpreting the concept of the message being transmitted. The sequence of learning to read is similar (LaBerge and Samuels, 1974). Motor skill acquisition also shows a complex buildup of skill to more complex levels (Welford, 1976). With extended practice one can do complex within process dual tasking such as reading. The beginning reader effortfully encodes each word and tries to comprehend it. The only time that a skilled reader may be aware of the dual task nature of reading is when the normal word encoding process is disrupted. For example, Kolers (1975) has had subjects read text in which each letter was inverted. When reading such text one divides resources between the encoding task and reading comprehension.[1] The concepts of resource pools can be utilized to describe within process dual tasking. In both within and between process dual task situations we often find that with extended practice those tasks which originally interacted, do not interact.

Dual process theories which assume that there are two qualitatively different forms of human information processing allow interpretation of the practice effect in dual task experiments. In the present paper these two forms will be referred to as automatic and controlled processing. Automatic processing is a fast, parallel, fairly effortless process which is not limited by short-term memory capacity, is not under direct subject control, and performs well developed skilled behaviors (see Schneider and Shiffrin, 1977; and Shiffrin and Schneider, 1977). Controlled processing is a slow, serial, capacity limited, subject controlled processing which deals with novel or inconsistent information. The proposal that there are two forms of information processing has had a long history in psychology (e.g., James, 1890) and has received considerable interest in recent years (LaBerge, 1973, 1975, 1976; Posner and Snyder, 1975; Norman, 1976; Shiffrin and Schneider, 1977; Logan, 1978, 1979; Hasher and Zacks, 1979). The automatic/controlled processing framework accepts the undifferentiated resource pool (Kahneman, 1973) or the multiple, somewhat differentiated resource pool (Wickens, 1980), as interpretations of how controlled processing may operate. The framework proposes that after extended practice in situations where subjects can consistently respond to the stimulus, information processing can be done by an automatic process which does not utilize limited controlled processing resources. A radical statement of this position would be that automatic processes can be done without any measurable cost. Hence, a subject should be able to perform two tasks simultaneously (assuming no incompatible responses, see Shiffrin and Schneider, 1977, pg. 161), as long as one of the tasks is an automatic process. This perspective would be appropriate to both within and between process dual task situations. Automatic processing should not be viewed as limited to simple detection tasks. We feel that the skill in complex behaviors such as chess pattern perception (Simon and Gilmartin, 1973), computer programming (McKeithen, Reitman, Rueter, and Hirtle, 1980), and X-ray interpretation (Swensson, 1979) is primarily in the form of developed automatic processes.

The automatic/control processing framework contrasts with the "attention is a skill" hypothesis (Spelke et al, 1976; Hirst et al, 1980) which proposes that extended time sharing training is sufficient to eliminate dual task interference. In situations where stimuli and responses are not consistently mapped dual task tradeoffs occur even after extended training (see Shiffrin and Schneider, 1977; Logan, 1979). The major emphasis in the "attention is a skill" hypothesis seems to be that very complex tasks can be combined without interference (Hirst et al, pg. 116). However, since automatic processes can be very complex (as long as responses are consistent within a given internal and external context), automatic processing can be as complex or subtle as nonautomatic processing. Hence we feel there is considerable agreement between the two approaches.[2]

The present series of experiments was designed to test whether automatic and control process tasks can be done simultaneously without cost in a between process dual task. Subjects were given extended practice in target detection to develop automatic processing. Subjects performed the automatic or controlled tasks either singly, or combined in dual task conditions. The experiments examine important dual task methodological questions relating to stimulus set choice, detection measure, criterion shifts, response probability, and inability

of subjects to protect the primary task. Experiments 8, 9, and 10 complete the series, showing that subjects can dual automatic and control process without any cost in sensitivity and they cannot dual control process without a substantial loss in sensitivity.

The experiments utilized a multiple frame procedure (Sperling, Budiansky, Spivak, and Johnson, 1971; Schneider and Shiffrin, 1977) which allowed independent manipulation of processing time, processing load, and number of channels. This allowed examination of dual task tradeoffs at a variety of difficulty levels. The experiments examined dual detection performance for a single target. In none of the conditions was more than one target presented per trial. Experiments already indicate that the processing of simultaneous targets (Moray, 1975; Shiffrin and Schneider, 1977) results in a deficit. This can be interpreted as the structural interference due to post target detection processing, and will not be studied in this series of experiments. The presence of automatic and controlled processing was manipulated by utilizing consistently mapped (CM), or variably mapped (VM) conditions. In the consistently mapped condition, the target and the distractor set are kept disjoint. Stimuli which are utilized as consistently mapped targets never appear as distractors. In the variably mapped condition, a stimulus which is a target on one trial can be a distractor on the next. CM conditions have been shown to develop an automatic processing referred to as automatic detection (see Schneider and Shiffrin, 1977). VM conditions have been shown to measure controlled processing performance. By simultaneously combining CM and VM search conditions, dual automatic and controlled processing performance can be monitored.

General Method

Equipment. All experiments were controlled by a Digital Equipment Corporation PDP 11/34 computer. The computer was programmed to present the appropriate stimuli, collect responses, and control timing of the display presentations. The stimuli were presented on Tektronics Model 604 and 620 cathode ray scopes. The scopes for Experiments 1 and 2 utilized a P-4 phosphor. The remaining experiments utilized the same scopes but with a P-31 phosphor. Each subject wore a headset through which white noise and error feedback tones were carried.

Stimuli. In the following experiments a sequence of 12 frames was presented on each trial. Each frame was configured such that four elements were positioned to form a square around a center fixation dot. The elements used in the various experiments were either upper case letters of the English alphabet, digits, random dot masks, or a combination of the above. Which elements were actually used will be reported for each experiment. The characters were constructed from dots on a rectangular grid 32 dots wide by 48 dots high. The center of each character was displaced .79 degrees horizontally and .79 degrees vertically from the focus dot. Each character subtended .58 degrees in width and .67 degrees in height. The random dot masks were similarly constructed. There were five different random dot patterns, each constructed by randomly placing 43 dots on the 32 by 48 dot matrix. The refresh rate of the dots making up the stimuli was 10 msec. The same character or mask was never presented in the same display position in two successive frames. Subjects sat approximately 40 cm from the display. In some experiments random dot characters were

presented between each frame to mask out the previous characters (see below).

Design. Four primary independent variables were manipulated. The number of characters in the memory set was either one or two. Frame time (symbolized by f), the time from the onset of one frame to the onset of the next frame (including the duration of any between frame masks), was varied between blocks. The relationship between the memory set and the distractor set was either consistent or varied in its mapping (denoted as CM and VM, respectively). The CM condition is so termed because the memory set items only occur as targets and never as distractors. The VM condition represents the condition in which memory set items on one trial may be distractors on another and vice versa. (See Schneider and Shiffrin, 1977, for a review.) The CM or VM conditions were manipulated between blocks of trials. There were three types of dual task search conditions manipulated between blocks: single VM search, single CM search, and dual CM/VM search. In single search conditions the subjects were to search, depending on the condition, only for CM or VM memory set items. In the dual CM/VM condition the subjects were presented with an item or items from their VM set in the memory set display. Subjects were not presented the potential CM items, instead two periods were presented, indicating that an item from the CM set might occur during the trial. In the dual search condition subjects were told to place all of their emphasis on the VM search condition and to report CM items if they saw them. In the combined search condition the occurrence of CM and VM targets was varied randomly between trials with the restriction that an equal number of CM and VM targets were to occur during the block. In the dual search conditions no more than one target could occur during a trial, hence dual CM and VM targets never occurred on a trial. In any of the search conditions, if a target occurred it could occur on any frame except the first two frames or the last frame of the trial.

The number of characters per frame, or frame size, was held constant at four across all experiments. The experimental conditions were manipulated within subjects. Detection accuracy was the primary dependent variable used for all experiments.

Procedure. Subjects in Experiments 8, 9, and 10 were generally run in a group of four with each subject's display independent of the others. In all other experiments the subjects were generally run in pairs, where the two subjects saw the same visual material (on different CRT's). Each trial was preceded by a presentation of the memory set. Subjects were given up to 30 seconds to study the memory set. Subjects initiated each trial by pushing a button with their left index finger. The display sequence began after both subjects had pushed their initiation button or 30 seconds had elapsed. Presentation of the frame sequence was preceded by a 500 msec display of the fixation dot. When a subject erred a tone, given through the subject's headset, and a red light, illuminated on the response box, indicated the error at the end of the trial.

Subjects. All subjects were paid for their participation, were right handed, had 20/20 or corrected 20/20 vision, and were students at the University of Illinois. All subjects reported English as their native language except for two subjects who participated in Experiments 1 and 2. Subjects participated in multiple experiments and had target search training before data collection

began.

Experiment 1: Dual Diagonal Letter Search

The automatic/control processing framework proposes that dual CM and VM processing can be done simultaneously without deficit. The present experiment required subjects to do CM search along one diagonal of the frame while simultaneously doing VM search along a second diagonal.

Method

Subjects. Three females and three males were employed as subjects in the present experiment. Prior to participating in this experiment the subjects had had extensive practice with the letter sets, experiencing approximately 25,000 trials.

Procedure. The manipulation of the independent variables was as described in the General Method. The type of search was single CM diagonal, single VM diagonal, or dual CM/VM diagonal. Memory set size was two for all conditions and frame time was varied between blocks being either 50, 100, 200, or 300 msec. In all search conditions a target was present on 50 percent of the trials. Each frame consisted of four letters positioned to form a square around a center fixation dot. The subjects were instructed to search one diagonal for the CM targets and the other diagonal for the VM targets. CM and VM diagonals were counterbalanced across subjects. The stimuli were a set of upper case letters which were randomly assigned to each subject. The letters were equally divided into two sets of six letters each, one being the CM set and the other the VM set.

On all trials the subjects were to press a button if they detected a target and were to push a different button at the end of the trial if no target was detected. Subjects pressed the "target present" and "target absent" buttons with either their right index or middle finger. Which finger was used for a given button was counterbalanced across subjects. Responses that occurred less than 150 msec after the occurrence of a target were treated as false alarms. The subjects were given up to 2.5 seconds to respond following the last frame of the target.

The first 10 trials of each block were considered practice and deleted from the analysis. Following the practice trials, each block contained 64 trials. All search and frame time conditions were replicated every twelve blocks. The sequencing of conditions within a group of twelve blocks (3 search conditions X 4 frame times) was randomly permuted. There were 768 observations per subject per block. Subjects completed approximately nine blocks per hour for a total of 144 blocks.

Results and Discussion

Figure 1 shows the results for replications 10-12 of each condition. Figure 1a shows the hits and false alarms as a function of frame time for both the CM and VM conditions. Figure 1b presents the results as a function of d'.

In the dual task conditions the hit rate for the CM and VM conditions was determined by the hit rate on those trials when there was a CM or VM target present, respectively. The observed false alarm rate when no target was present was assumed to be the false alarm rate for both the CM and VM condition. Since the CM and VM single false alarm rates were equal, the assumption of equal false alarm rate in the dual task has some support (however, Experiment 8 indicates this assumption is inappropriate). Figure 1c plots the same data using A' as a measure of detection sensitivity (Norman, 1964; Craig, 1979). A' is a measure of the area under the ROC curve ranging from .5 for chance detection to 1.0 for perfect detection. The A' measure is a somewhat more distribution free measure of detection sensitivity, and seems a more appropriate measure when false alarm rates get very low as they do in some of the following conditions. Figure 1d presents the performance operating characteristic (POC) curve of the A' results for the single and the dual task experiments. This method of plotting dual task data (Norman and Bobrow, 1976) provides a graphic illustration of tradeoffs between dual task conditions. If there is no tradeoff between conditions, each frame time should be represented by a rectangle on the POC curve. If there is a complete tradeoff between conditions, the POC curve should be a straight line from the VM single, to the dual VM/CM point, to the CM single condition. There are 480 observations per point in the single search conditions, and 240 observations per point in the dual search conditions. Hence, the expected standard deviation in hit rate is less than 3%.

Insert Figure 1 about here

The CM conditions are superior to the VM conditions whether the measure is hits, d', or A', or whether you compare single or dual task performance. The dual task decrement for the CM condition is 7% hit rate, and for the VM condition 11% hit rate. The POC A' curves are clearly not rectangular, showing both a decrement in performance in the dual task search and a tradeoff in performance. Subjects were unable to protect their dual task performance. Individual subjects differed somewhat. One subject who did maintain the VM hit rate, dropped 9.5% in CM hit rate. A subject who maintained the CM hit rate, dropped 5% in the VM hit rate. During the practice period of the experiment, subjects' performance improved substantially, but the dual task performance is clearly not equal to the single task performance.

Assuming the hypothesis that dual CM and VM search can be done without cost, there are several potential interpretations of the present results. The inability to protect the emphasized VM task could result from false alarms occurring on the CM diagonal which attract attention from the VM diagonal characters. Previous research suggests that CM false alarms could cause such a distracting effect (Shiffrin and Schneider, 1977, Experiment 4d). This is tested in Experiments 2, 7, and 8. A second interpretation is that pure automatic processing might occur only when the stimulus sets are well defined, and a current choice of letters did not allow subjects to develop good automatic processes. This assumption is tested in Experiments 3 and 4. A third interpretation is that subjects are unable to split automatic and controlled processing resources to different portions of the visual field. This assumption is tested in Experiments 2 and 4. A fourth interpretation tested in Experiment 7 assumes the dual task deficit is the result of reduced target probability in

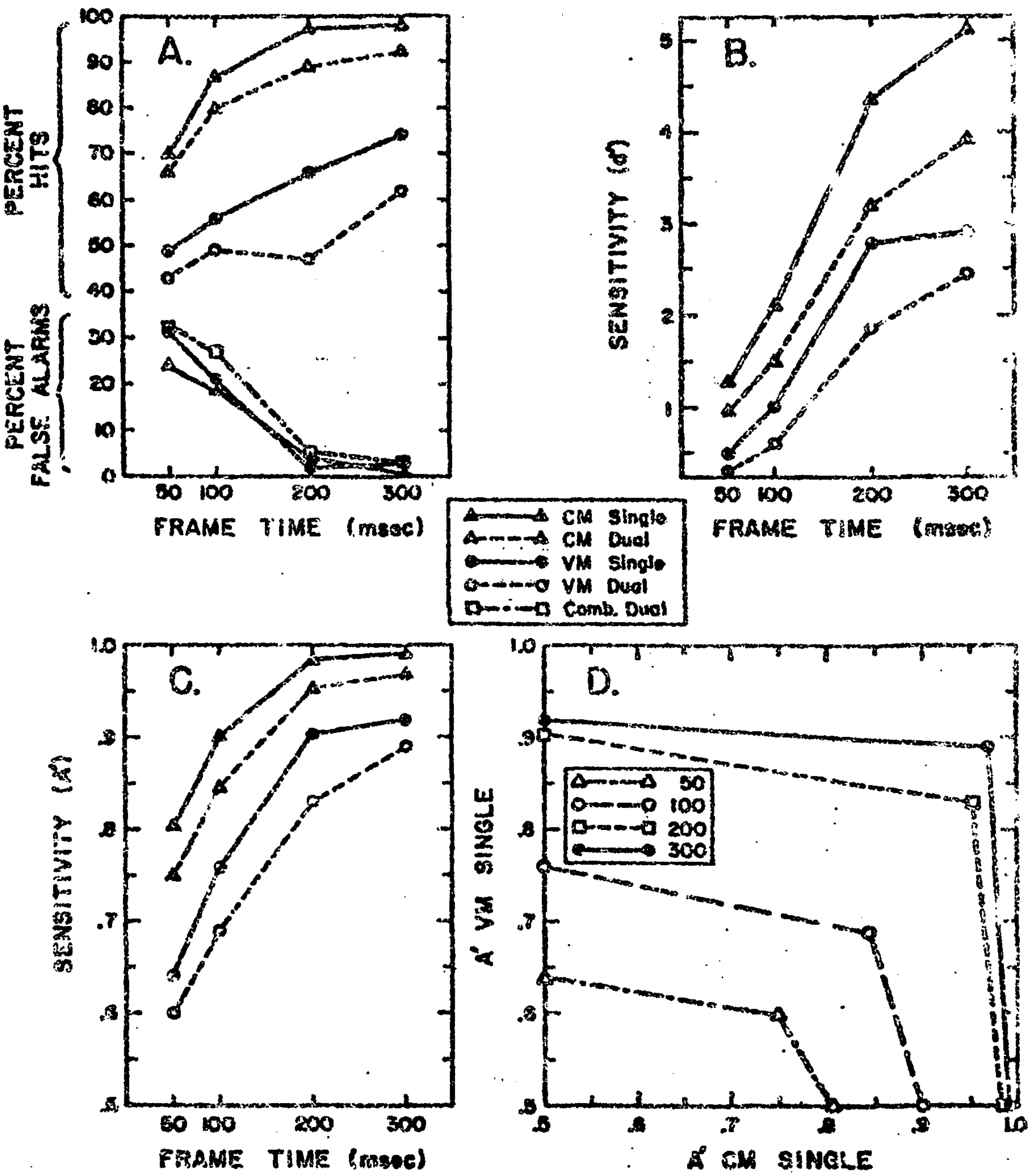

Figure 1. Experiment 1 dual diagonal CM/VM, memory set size 2 letters, replications 10-12. 1a - hits and false alarms as a function of frame time. 1b - d' as a function of frame time. 1c - A' as a function of frame time. 1d - performance operating characteristic curve A' for single and dual task.

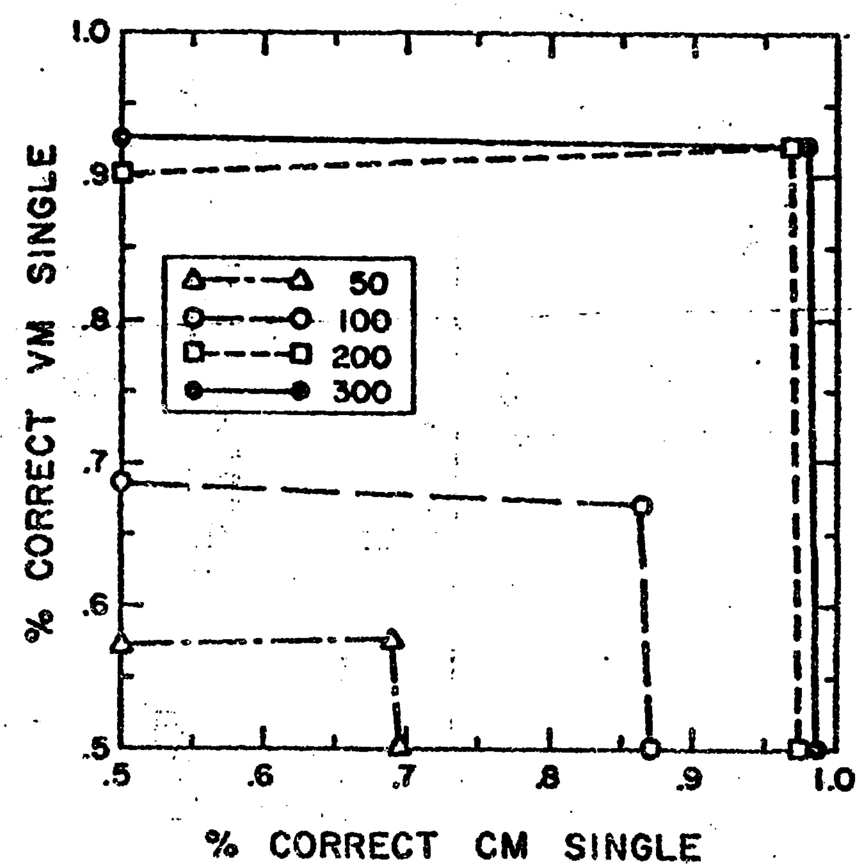

Figure 2. Experiment 2 POC A' curves for CM and VM search, replications 2-6.

the dual task conditions. A fifth interpretation is that subjects may have had a severe criterion shift when going from the single to the dual task. This is tested in Experiments 8, 9, and 10.

Experiment 2: Dual Non-diagonal Letter Search

In Experiment 1 subjects in the dual task condition complained about the difficulty of splitting their attention across the two diagonals and about occasionally having their attention attracted to the non-emphasized (CM) diagonal. The present experiment required subjects to look for either CM or VM targets in any of the four positions of the display. In Experiment 1's dual diagonal search condition, a CM false alarm would be expected to reduce the VM performance because the false alarm processing would utilize resources on the non-emphasized diagonal. In this experiment all conditions must be processed for both CM and VM targets. Hence, if a false alarm causes one position to be evaluated before other positions, it would be expected to have little effect on performance.

Method

Experiment 2 was conducted in the same manner as Experiment 1 with the following exceptions. The diagonal search requirement was removed which allowed a target to occur in any display position of the target frame. As in Experiment 1 the assignment of the target display position was random. The frame time was 50, 100, 300, or 500 msec, being varied between blocks.

Excluding the 10 practice trials, each block contained 64 trials. Twelve blocks were needed to complete a replication. There were 6 replications. The subjects were the same as those used in Experiment 1.

Results and Discussion

Figure 2 shows the A' POC curves for replications 2 through 6. In this condition there was very little dual task performance decrement. For all frame times except f=100, the single and dual CM/VM conditions were equal. The dual VM search hit rate for frame time equal to 100 msec was 7% below the VM single hit rate. The dual CM hit rate was .5% better than the CM single hit rate. The CM single false alarm rate was 6% less than the VM false alarm rate, and the dual false alarm rate was about 2% less than the CM single false alarm rate. The average A' difference of single versus dual task performance was .003 A' units improvement for VM dual and a .011 A' unit decrement for CM dual, both of these differences were nonsignificant. All subjects showed little or no dual task tradeoff, and were able to maintain dual VM detection performance at the same level as single VM performance. The rectangular POC curves indicate that subjects can perform joint automatic and controlled processing with little or no deficit given that both processing modes are allocated to processing the same locations.

Insert Figure 2 about here

Experiment 3: Dual Letter Number Search

The present experiment examines whether greater featural differences will enable subjects to do dual diagonal automatic and controlled search without cost. Automatic search may require greater featural differences in order to be effective. The subject who was best able to perform CM search in the first experiment, was also best able to maintain performance in the dual task condition. Experiment 3 examined CM category search for numbers in letters (or vice versa). Previous research has indicated that good automatic processing development occurs in this type of search (see Schneider and Shiffrin, 1977). The present experiment eliminates the ceiling and floor effect problems of the first two experiments. Experiments 1 and 2 utilize memory set size of two. This made the CM performance far superior to the VM performance. For most of the frame times, CM was either near ceiling or VM near floor. The present experiment utilizes memory set size of one so that ceiling and floor effects are less of a problem.

Method

Procedure. The procedure was the same as the previous experiment with the following differences. Five buttons on the response keyboard were utilized. Four of the buttons were in the lower right of the keyboard and formed a square that corresponded to the display positions of the stimuli. The remaining button, the initiation button, was located in the upper left portion of the keyboard.

There were two sets of seven characters (1, 2, 3, 5, 6, 8, 9 and A, C, E, M, R, S, Z). These letters were chosen as stimuli because of their relative equal confusability within the set.[3] One set was the CM target set, the other the CM distractor set and VM set. Stimulus sets were crossed across subjects.

A frame in the present experiment consisted of the presentation of four characters for a given duration and immediately following the termination of the character display was a presentation of four random dot masks. The dot masks occupied the same display positions as the characters. The display time of the intervening dot masks was constant at 50 msec. The characters were displayed for either 50, 130, or 200 msec, giving total frame times of 100, 180, or 250 msec, respectively. The frame times were varied between blocks.

All trials contained a target. The subject's task was to determine in which display position the memory set item had occurred and to push the corresponding button on the response keyboard. The subjects used their right index finger to make their response. The target could occur in any display position as in Experiment 2.

A one second error tone occurred when the subject was incorrect concerning the target's location. Feedback was given to the subject concerning his cumulative accuracy for each current block. This feedback was given by presenting, along with the memory set, a two digit number indicating percent accuracy.

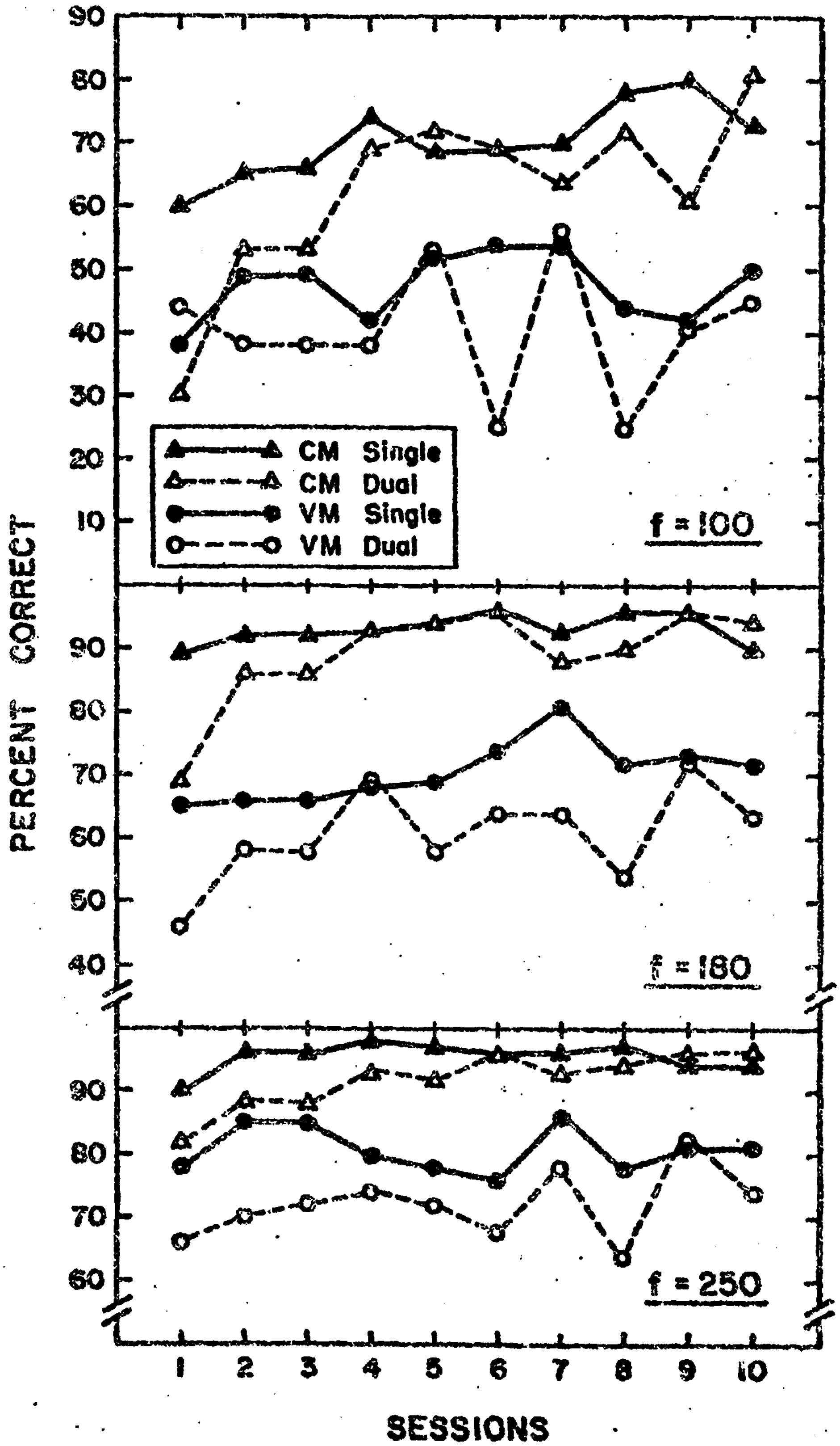

Figure 3. Experiment 3 corrected position identification across sessions for single and dual task performance.

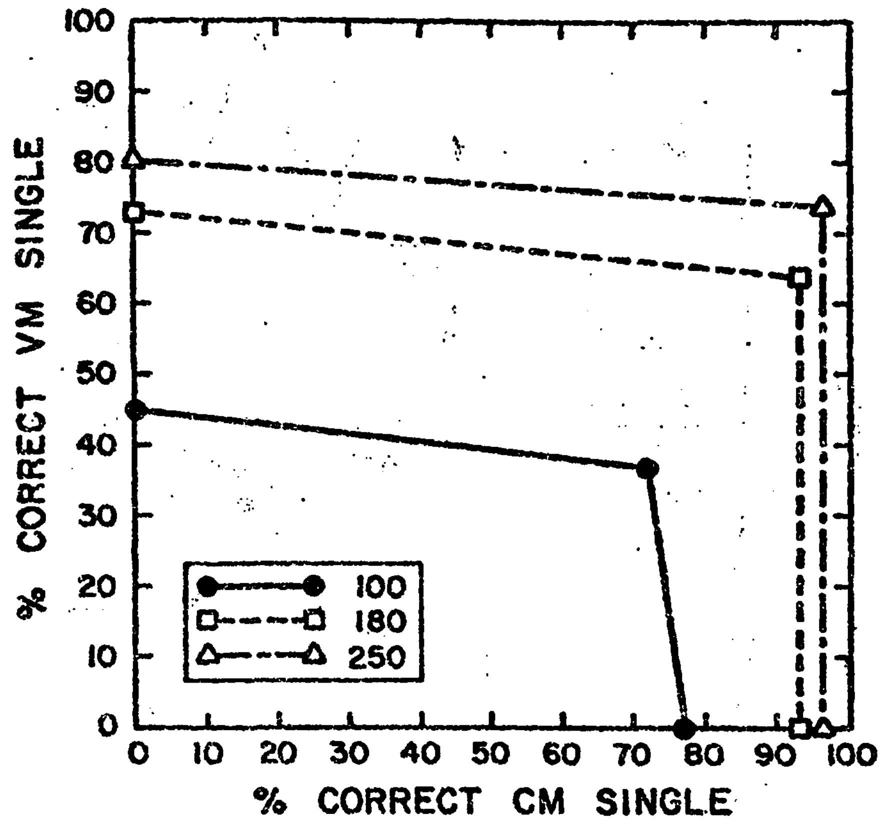

Figure 4. Experiment 3 POC corrected position identification curves for single and dual task sessions 4-10.

Disregarding the 10 practice trials, each block contained 48 trials. A session consisted of nine blocks (3 frame times X 3 dual search conditions).

Four subjects were employed in the present experiment. They had not participated in the previous experiments. These subjects were used in all remaining experiments except Experiments 9 and 10.

Results and Discussion

Figure 3 shows the corrected position accuracy (percent correct minus one-third percent error) as a function of sessions. The CM conditions improve with practice. Dual task CM condition improves sharply with practice during the first four sessions of the experiment. Sessions 4 through 8 are particularly unstable due to subjects participating with little sleep (when subjects were asked about their performance, 2 of the 4 subjects said that they had had less than four hours of sleep the night before participating due to exams). For sessions 4 through 10 there is an average 2 percent dual task deficit in CM performance and an average 8 percent deficit in dual task VM performance. If sessions 6 through 7 are deleted the VM decrement is only 4 percent.

Insert Figure 3 about here

The dual task CM decrement is eliminated with practice, but the dual task VM decrement remains. During this time subjects were strongly encouraged to protect their VM performance (subjects were reprimanded for not maintaining dual task VM performance, they were given their scores, and they were told not to be concerned about CM performance in the dual task situation). It is important to note that the stimulus presented on a dual task VM trial is exactly the same as the stimulus presented on a single task VM trial. Results suggest that there is either some cost of enabling the automatic CM search, or that subjects are wasting some of the controlled processing on the CM search task during dual task search.

Experiment 3 (Figure 4) shows some (8%) dual task deficit in VM non-diagonal search whereas Experiment 2 (Figure 2) did not. This difference is probably accounted for by the comparatively little CM training received by subjects in Experiment 3 versus Experiment 2 (about 800 versus 12,500 trials).

Insert Figure 4 about here

Experiment 4: Dual Diagonal Number Letter Search

This experiment examines subjects' ability to split their attention across diagonals in a dual CM and VM search. In addition, subjects were required to make confidence ratings as to their confidence of specifying the potential target position.

Method

This experiment utilized a digit letter search procedure similar to Experiment 3 except for the following changes. The present experiment used the diagonal search procedure that was described in Experiment 1. The probability of a target was .5.

The major difference between the present experiment and those described previously was that subjects were required to indicate their confidence concerning their response. After indicating the target's position the subjects pushed one of four numbered buttons to indicate their degree of confidence. The subjects' confidence rating of the target position ranged from 4 to 1. The meaning of each confidence button was: 4) The subject was sure the target was present and was sure of its location; 3) The subject thought the target had occurred but was unsure of its location; 2) The subject was unsure the target had occurred; and 1) The subject was sure the target had not occurred. The subjects were given up to six seconds to indicate the target's position and enter a confidence rating for that response. Beginning with the current experiment, only VM accuracy was indicated to the subject in the dual CM/VM condition.

Excluding the 10 practice trials, each block contained 56 trials. Nine blocks were required to complete a session (3 frame times X 3 search conditions). There were a total of 10 sessions.

Results and Discussion

The corrected position identification POC curves for sessions 7-10 are presented in Figure 5. There is a substantial dual task CM deficit of 24, 10, and 2 percent, respectively, for frame times 90, 130, and 180 msec. The VM dual task decrement is 2. 6, and 12 percent for the same frame times.

Insert Figures 5 and 6 about here

In order to determine whether subjects are trading off VM performance for CM performance, each session was analyzed to find the session with the greatest and smallest VM single minus dual task differences. Figure 6 plots the average CM difference that occurred for each subject on the session with the greatest and smallest VM difference. If subjects were trading off VM performance to improve CM performance, the sessions with the largest VM difference should have the smallest CM difference. However, the sessions with the largest VM difference had the largest CM difference. This suggests that subjects were not directly trading off CM performance for VM gain.

The confidence ratings were unstable due to subjects making relatively few responses at the confidence rating levels of 3 and 2. Subjects became an average of .16 less confident when moving from CM single to CM dual. Subjects were an average .2 units less confident about no target responses in the dual versus single task conditions. There was no effect on the confidence ratings when moving from VM single to VM dual (see Table 1). Subjects were more confident about CM targets than VM targets in the dual task, and were more confident of the occurrence of a CM target than a VM target. This suggests subjects may be more conservative about responding on the CM diagonal.

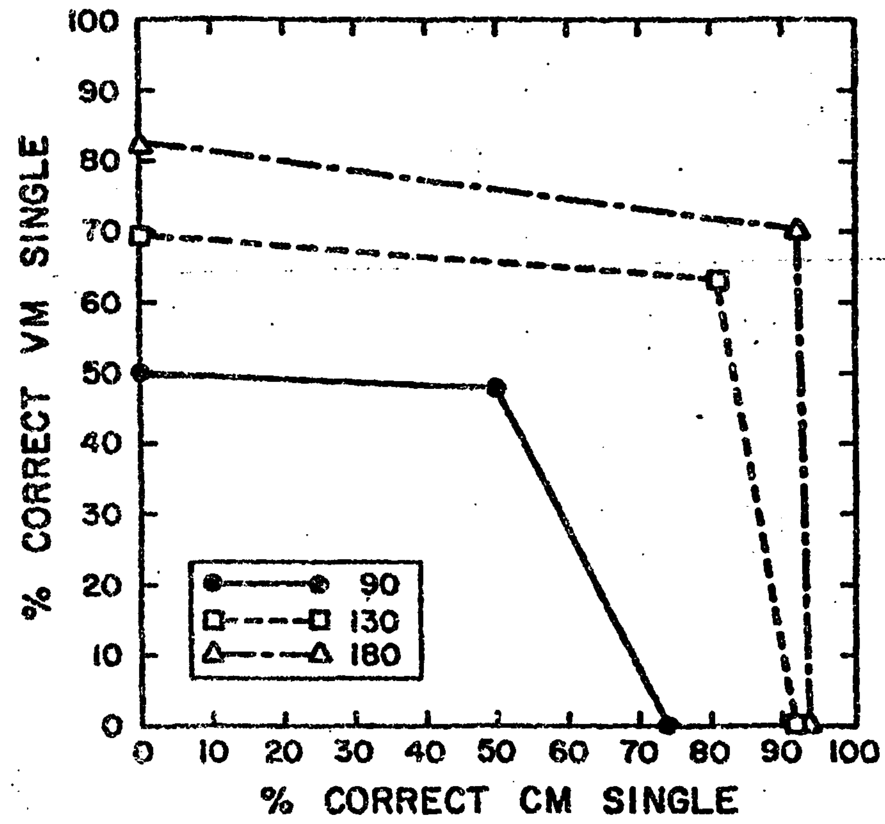

Figure 5. Experiment 4 corrected position identification single and dual task sessions 7-10.

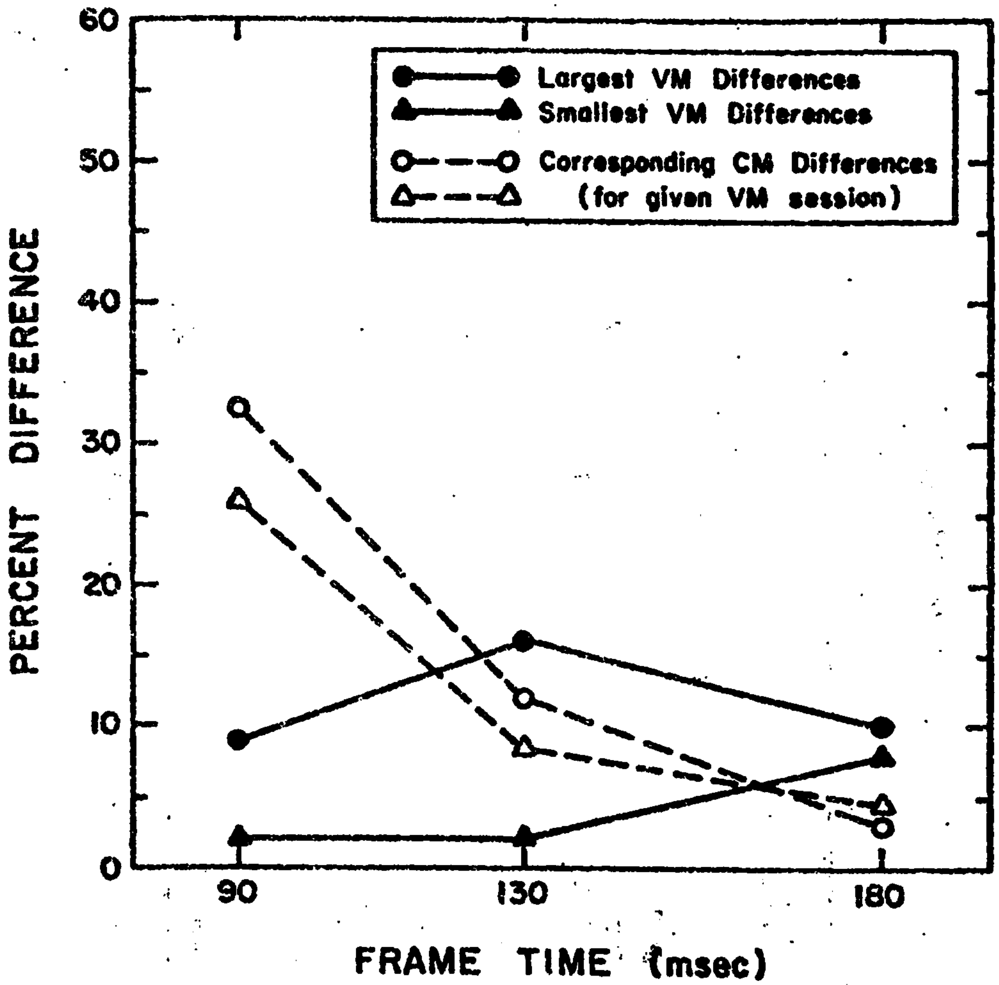

Figure 6. Experiment 4 plot of single versus dual task difference for the session with the largest and smallest VM difference in each condition. Each subject's data was analyzed separately and the average graph sums different sessions for different subjects.

Table 1

Experiment 4 confidence rating sessions 7-10

Rating 4 - certain target and position, 1 - certain no target

	Target Present				Target Not Present		
Frame Time	CM Single	CM Dual	VM Single	VM Dual	CM Single	VM Single	CM/VM Dual
90	3.55	3.31	3.21	3.31	2.29	2.14	2.49
130	3.90	3.72	3.41	3.39	1.66	1.86	1.97
180	3.96	3.88	3.60	3.54	1.42	1.56	1.60
Average	3.80	3.64	3.41	3.41	1.79	1.85	2.02

Table 2

Dual CM/VM drop vs Dual VM drop

Frame Time	Experiment 3 VMS	VMS-VMD	CMS-CMD	Experiment 5 VMDM	VMS-VMDM
100	.47	.08	.06	.29	.18
180	.71	.09	.00	.54	.17
250	.80	.06	.00	.60	.19
Average	.66	.08	.02	.48	.18

VMS - single VM search, VMD - VM search in dual VM/CM search
CMS - single CM search, CMD - CM search in dual VM/CM search
VMDM - VM memory set size 2 search

Insert Table 1 about here

This experiment shows primarily a CM dual task deficit, whereas Experiment 1 showed primarily a VM dual task deficit. Subjects were less practiced in this experiment than in Experiment 1, however this is unlikely to have been the reason for the effect. A more likely explanation for the drop in CM performance is a greater emphasis on the VM performance. In this experiment subjects were given no feedback on their CM dual task performance and were strongly encouraged to maintain VM performance. This may have caused subjects to become more conservative about responding on the CM diagonal, which would have reduced hit rate but not necessarily target detection sensitivity.

Experiment 5: Dual VM Search

Experiments 2 and 3 showed little dual task decrement for joint automatic and controlled processing of all four display positions. To put this dropoff in perspective, it would be useful to know what the dropoff would be for dual controlled process search. The present experiment examined performance when subjects were asked to search for two control process (VM) targets.

Method

The procedure in Experiment 5 was the same as that described in the General Method and Experiment 3 with the following exceptions. Only the characters from the subjects' VM set were used as stimuli and the memory set size was two. Hence, subjects had to search four positions with a memory set size of two, indicating the position of the target. Only this dual VM condition was run.

Results and Discussion

The results are presented in Table 2. Compared to the single controlled process search in Experiment 3 (VMS), the dual controlled process position accuracy dropped 18 percent. This can be contrasted with the average 8 percent VM deficit seen in Experiment 3. The VM deficit in Experiment 3 excluding sessions 6 and 7 (due to subjects performing while sleepy, see Experiment 3) was only 4 percent. The results clearly indicate that searching for any CM character (e.g., any digit) and a VM target (e.g., a specific letter) is easier than searching for two VM targets (e.g., two letters). Dual control task processing is more difficult than dual automatic and controlled task processing.

Insert Table 2 about here

Experiment 6: Automatic Processing Emphasis in Dual Diagonal

This experiment determines the effect on controlled process search if emphasis is shifted to the automatic process diagonal in a dual diagonal search. The automatic/control processing framework would predict that this change in

emphasis should result in a severe control process performance decrement. Since the control process performance is resource-limited, any reallocation of controlled processing resources should produce a decrement in the controlled process task. The framework would also propose that the allocation of controlled processing resources to the automatic process should not substantially improve its performance.

Method

The dual search condition was the same as that described in Experiment 4 except that the search emphasis was switched from the VM to the CM diagonal and only the dual task conditions were run. Each block contained 48 trials with the frame time replicated every 3 blocks. Subjects completed five of these replications in two 50 minute sessions.

Results and Discussion

There was a 32% decrement in dual task control processing position accuracy (see Figure 7). This is considerably greater than the 13% dual task decrement seen in Experiment 4. Three of the four subjects in the present experiment were at chance in the unemphasized control process for the 90 and 130 msec frame times. Since the automatic processing diagonal search is relatively resource insensitive, subjects may have been allocating resources to the control process diagonal, even if that diagonal was not emphasized. The present data indicates that without being emphasized, the dual task control process accuracy drops severely. Comparing Figures 5 and 7 illustrates the resource insensitivity of automatic processing and the resource sensitivity of control processing.

Insert Figure 7 about here

Experiment 7: Ignoring CM Target Control

In the previous experiments, subjects have been unable to protect their dual task control processing performance. In these experiments subjects are given contradictory demands. They are requested to allocate all of their resources to the control process, but if they do see an automatic process target, they are to to respond to it. The present experiment specifically instructs subjects to ignore any automatic process targets that occur in some conditions. In addition, this experiment clears up a target probability confounding in the previous experiments. In the previous experiments the targets occurred with probability of .5 in the single and dual task conditions. This meant that the probability of a CM or VM target reduced from .5 to .25 when moving from the single to the dual task situation. The present study maintains the probability of a target at .25 in all conditions.

Method

The procedure for the present experiment was generally the same as described in Experiment 4. The design of the present experiment was different from Experiment 4 in the following ways. The memory set display and the trial

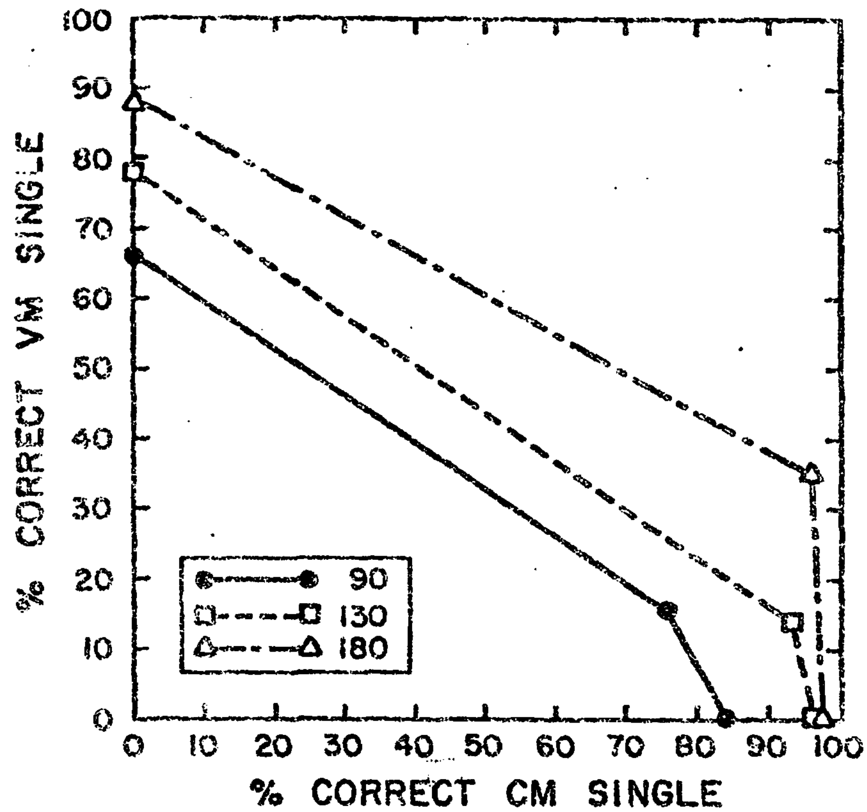

Figure 7. Experiment 6 POC of position accuracy with emphasis on the CM diagonal sessions 1-5. The CM and VM single conditions are the data from Experiment 4 sessions 8-10.

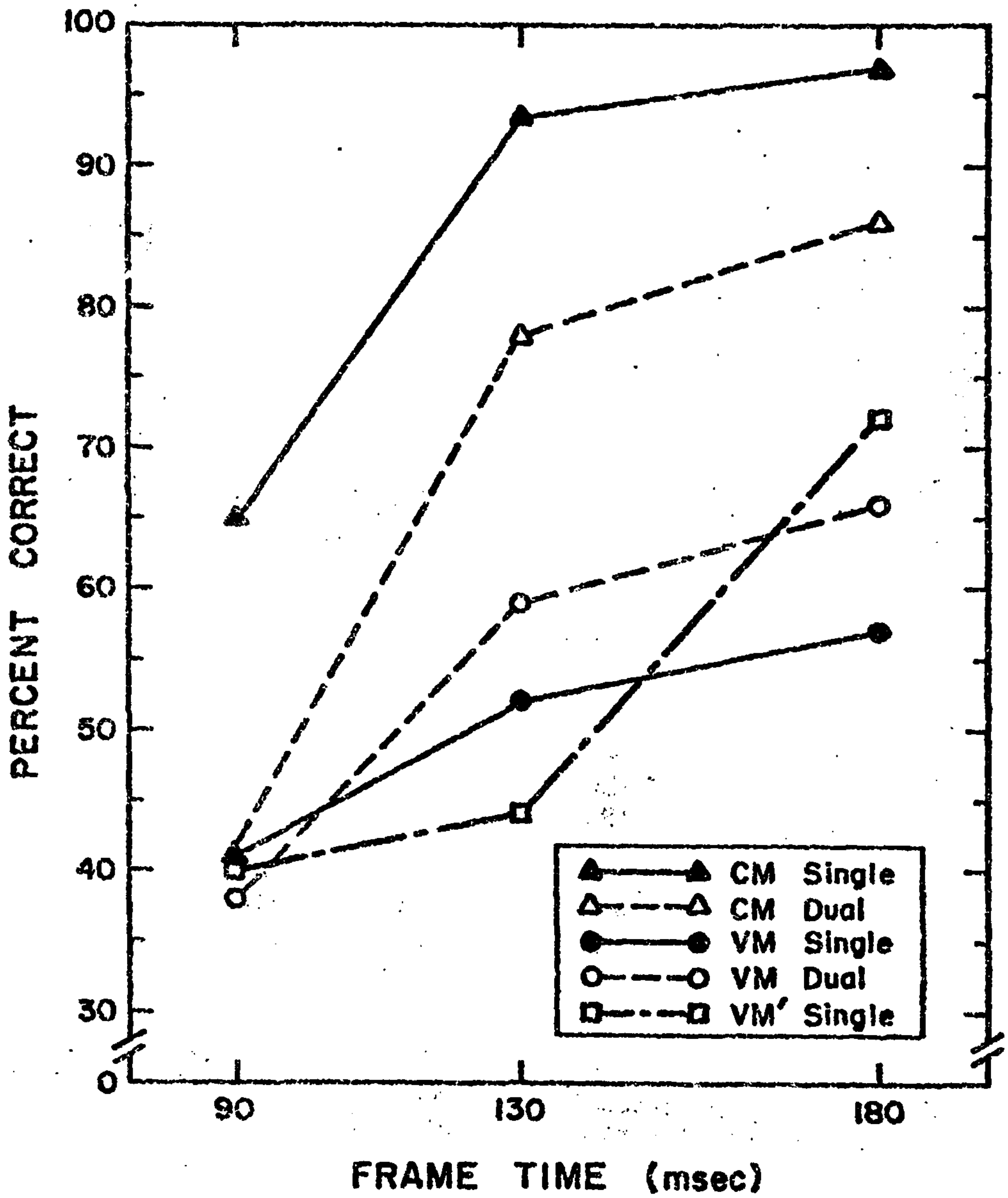

Figure 8. Experiment 7 accuracy as a function of frame time for sessions 3-6. VMS' is the single VM condition in which CM targets occur but are to be ignored. All other conditions are similar to previous conditions.

sequence, for all conditions, appeared as it did in the dual search condition of Experiment 4 except that a number (1, 2, or 3) was presented below the memory set display (separated by a dotted line). This number indicated the current search condition to the subject. Search condition 1 meant the subjects were to search their CM diagonal and to ignore the VM diagonal. Search condition 2 required the subjects to search their VM diagonal and to ignore the occurrence of any CM items that occurred on their CM diagonal. This condition actually consisted of two VM single search conditions. One, denoted as VM' single, did in fact contain the occurrence of CM items. The other, VM single, never contained CM items. Subjects were not made aware of this distinction. In the CM and VM conditions, where subjects were to ignore the occurrence of the other memory set item, the "ignore" item did not occur on the same trial as the valid memory set item. The final search condition, condition 3, was a dual search condition constructed as in Experiment 4.

All conditions were run in blocks of 48 trials. In the dual search condition 50% of the trials did not contain a target, 25% contained a CM target, and 25% contained a VM target. The single conditions consisted of 75% no target trials and 25% target trials. All search and frame time conditions were replicated every 12 blocks. Subjects participated in six of these replications completing about 10 blocks per hour. If subjects did not see a target, they were to guess as to the position of a target (even on trials when no target was present).

Results and Discussion

Figure 8 graphs the accuracy as a function of frame time in each of the conditions. The main effects of experimental conditions ($F(4,12)=9.12$, $p<.002$), frame time ($F(2,6)=13.15$, $p<.007$), and the interaction ($F(8,24)=5.79$, $p<.0004$) were significant. For the VM conditions experimental conditions ($F(2,6)<1$) and interaction ($F(4,12)=2.22$, $p>.1$) were not significant and the frame time effect was ($F(2,6)=8.13$, $p<.02$). The VM dual condition averages 4% better than the VM single condition. The VM single while ignoring CM targets is equal to the VM single condition. were The CM dual condition dropped an average of 17%. For the CM conditions the experimental conditions ($F(1,3)=29.86$, $p<.02$) and frame time were significant ($F(2,6)=8.13$, $p<.02$) but the interaction was not ($F(4,12)=2.22$, $p<.1$).

Insert Figure 8 about here

The change in VM target probability between Experiment 4 and the present experiment caused a substantial reduction in VM detection. Comparing the VM single condition of the present experiment with the similar VM single condition of Experiment 4, the present VM single condition is an average of 15.3% worse. The only differences between these conditions are greater CM practice and that the target probability has reduced from .5 to .25 in the VM single condition. This suggests that the major cause of the dual task controlled process decrement seen in the previous experiments was due to the change in the probability of a controlled process target. Note the change in CM single target probability from .5 to .25 did not affect CM single detection accuracy (CM single results from Experiments 4 and 7 were equal).

The present results allow three conclusions. First, subjects can do a substantial amount of automatic processing with no cost to concurrent control processing. Second, the effect of false alarms from the to-be-ignored automatic process targets is minor (there was no difference between VMS' and VMS). Third, when utilizing a corrected accuracy position measure, there is still an automatic process drop in performance in dual diagonal dual task automatic and controlled processing.

Experiment 8: Division of CM and VM False Alarms

With the measures utilized in the previous experiments, a substantial shift to a more conservative criterion in dual process automatic processing could result in a substantial decrease in the measured automatic process performance. In Experiment 5 subjects became less confident in their target position ratings as they shifted from the single to dual task CM search conditions. The corrections utilized in Experiments 3-7 correct only for guesses. If a subject has a severe criterion shift and produces no responses on the CM diagonal, a decrement in the CM position accuracy will occur. In fact, one subject in Experiment 4 made no responses in one of the CM dual diagonal conditions, indicating a substantial conservative criterion shift. A criterion shift argument also provides an interpretation for the lack of dual task decrements seen in the non-diagonal conditions. In the diagonal search conditions subjects would set a higher criterion for responding to the nonemphasized (CM) diagonal. In non-diagonal search, the criterion to respond to a given position should be equal for each position in all conditions. The present experiment seeks to test for a bias shift that reduces the effect of hit rate on the CM diagonal.

Method

Experiment 8 was conducted in the same manner as the previous experiment except subjects were to indicate whether they thought a given trial contained a CM target, VM target, or no target. Subjects continued to make position judgements. This rating replaced the confidence rating of Experiment 7. The data of this experiment were stored such that in the dual condition CM and VM false alarms could be differentiated.

Results and Discussion

The A' POC curves are rectangular showing no dual task tradeoff in either the CM or VM task (see Figure 9). If a d' statistic is used (see Table 3), there is actually a dual task CM improvement in performance. Although it is possible that an automatic process may perform better without any control processing allocated to it, the present dual task improvement in d' sensitivity is probably due to inappropriateness of the d' measure at very low false alarm rates in the present experiment.

Insert Figure 9 and Table 3 about here

Table 3 shows a very substantial criterion shift in the CM conditions, but not in the VM conditions. The dual task CM criterion shift is 69 units (beta of

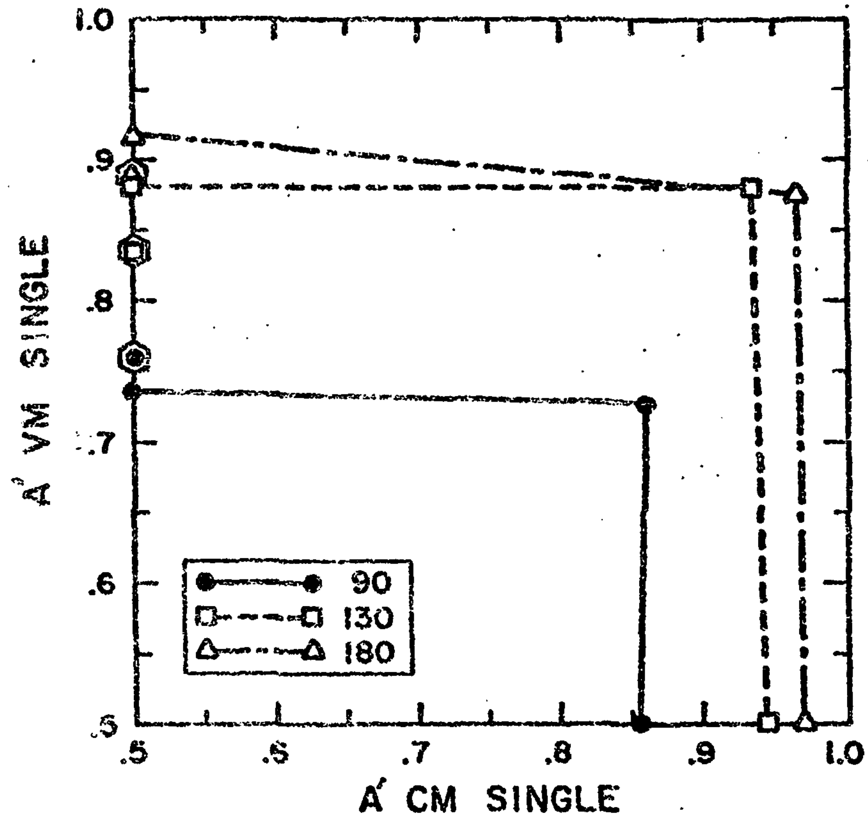

Figure 9. Experiment 8 A' POC for sessions 5-7. The boxed points on the CM single axis represent the VMS' condition in which CM targets appeared but were ignored by subjects.

Table 3

Experiment 8 d'

Frame Time	VMS	VMS'	VMD	CMS	CMD
90 d'	.96	1.02	.88	1.63	1.93*
130 d'	2.05	1.75	1.92	3.13	3.41
180 d'	2.54	2.03	2.15	3.62	4.98
Average d'	1.85	1.60	1.65	2.79	3.44
90 β	2.16	1.74	1.87	1.21	88.95*
130 β	4.49	4.92	2.83	2.15	78.39
180 β	4.01	3.51	5.87	1.81	46.16
Average β	3.55	3.39	3.52	1.73	71.16

*Excludes subject number 1 due to no hits in this condition.

CMD-CMS). There was no criterion shift in the VM conditions (VMD-VMS=-.022, VMD-VMS'=.135). These results show that when subjects are asked to strongly emphasize the control process diagonal, there is a severe criterion shift on the automatic process diagonal.

The present results indicate that subjects can perform dual task automatic and controlled processing with no cost in terms of sensitivity. There is, however, a substantial conservative criterion shift in the automatic process task when subjects emphasize the controlled process task. If an analysis is done collapsing the CM and VM false alarms of the present experiment, the results show the same dual task CM decrement seen in Experiment 1. This suggests that the dual task decrements seen in Experiments 1-4 and 7 (which were not set up to find beta shifts) were due to a dual task criterion shift. The hypothesized result that dual automatic and controlled processing can be done without cost, has been demonstrated. Results indicate that subjects can perform dual detection operations in differential retinal locations without cost, given that one is an automatic and the other is a controlled task.

Experiments 9 and 10: Dual Controlled Processing

The present experiments examine dual controlled processing deficits utilizing the same methods as Experiment 8. The purpose of the present experiments is to draw out a portion of the dual control process task performance operating curve. This will allow some interpretation of the resource sensitivity of these processes (see Navon and Gopher, 1979). The attention is a skill hypothesis (Hirst et al, 1980) suggests dual VM search could also be done without deficit, automatic/control processing theory suggests it cannot be.

This experiment contained three VM search conditions. In the single search condition subjects were required to search a given diagonal for the occurrences of the VM memory set item. There were two "dual" search conditions. One dual condition contained a memory set size of one with the memory set item randomly occurring on either diagonal. The other dual condition used a memory set size of two with each memory set item assigned to a different diagonal. The memory set display configuration indicated the current search condition to the subjects. Consistent with Experiment 8, subjects made two responses. They indicated the position of the target, then they indicated on which diagonal they thought the target had occurred or that it was a no target trial. Subjects' performance was scored in terms of CM hits, CM false alarms, VM hits, and VM false alarms. Hence a VM false alarm was treated as a CM correct rejection and vice versa.[4] The VM single condition consisted of 75% target absent and 25% target present trials. In the dual conditions 50% of the trials did not contain a target, 25% of the targets occurred on one diagonal and 25% on the other.

In the Experiment 9 dual conditions, subjects were instructed to emphasize their search on the diagonal which they searched in the single search condition. Which diagonal was to be emphasized was counterbalanced across subjects. Experiment 10 was the same as Experiment 9 except subjects were instructed to use equal emphasis.

Four new subjects were recruited for Experiments 9 and 10. These subjects were summer students at the University of Illinois.

Results and Discussion

The results are presented in Figures 10 and 11. Subjects were able to maintain their controlled process performance on the emphasized diagonal (see Figure 10). However, there was a substantial deficit in the unemphasized diagonal. For memory set size one A' dropped an average of .15 A' units, and for memory set size two it dropped .26 A' units. This is by far the largest drop we have seen in any experiment. When given equal emphasis there is still a substantial deficit in processing of either diagonal (see Figure 11). It should be noted that there is still a bias toward the emphasized VM diagonal. Subjects did not equally distribute their processing resources as requested (the dual process A' curves are closer to the previously emphasized axes than the other axis). Whether or not subjects can equally distribute resources after many hours of emphasizing one diagonal, is yet to be determined empirically.

Insert Figures 10 and 11 about here

The A' curves are not linear as would be expected in a direct tradeoff between the two tasks. However, this lack of linearity in the POC curves is difficult to interpret. A' is not a linear measure. Specific models of resource allocation will have to be applied to this data before one can say whether there was or was not a direct tradeoff between processing on the two diagonals.

General Discussion

The present results confirm the hypothesis that joint automatic and controlled processing can be done without cost. Figure 12 provides a representation of the signal and noise distributions and the response criterion effects which could have produced the results seen in Experiments 1-10. In the consistently mapped condition there is no sensitivity difference between the single and dual task conditions. However, if emphasis is placed on the VM dual task condition, there is a strong conservative criterion shift in the CM condition. In the variably mapped condition, there is no shift in sensitivity or criterion when moving from the single task to the dual task with emphasis on the VM task condition. However if emphasis is switched to the CM condition, there is both a decline in detector sensitivity and a criterion shift. Once the effects of criterion shift have been taken into account, automatic and controlled processing can be combined without sensitivity cost, given emphasis is placed on the controlled processing task.

Insert Figure 12 about here

In dual automatic and controlled processing tasks, subjects have a tendency to waste controlled processing on the automatic processing task. Throughout all the dual task experiments, subjects had a great deal of difficulty maintaining

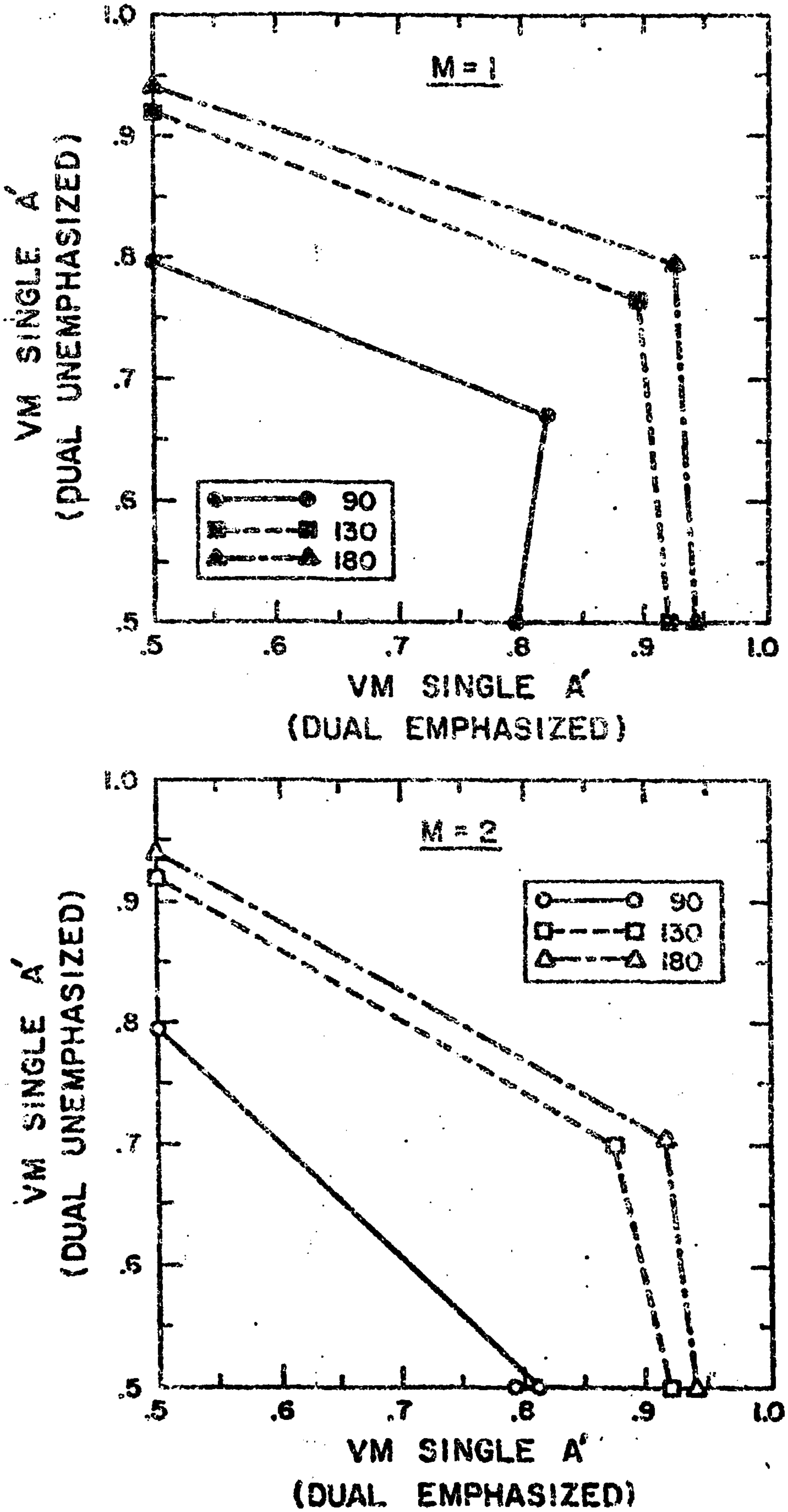

Figure 10. Experiment 9 A' curves for dual control processing search sessions 3-7.

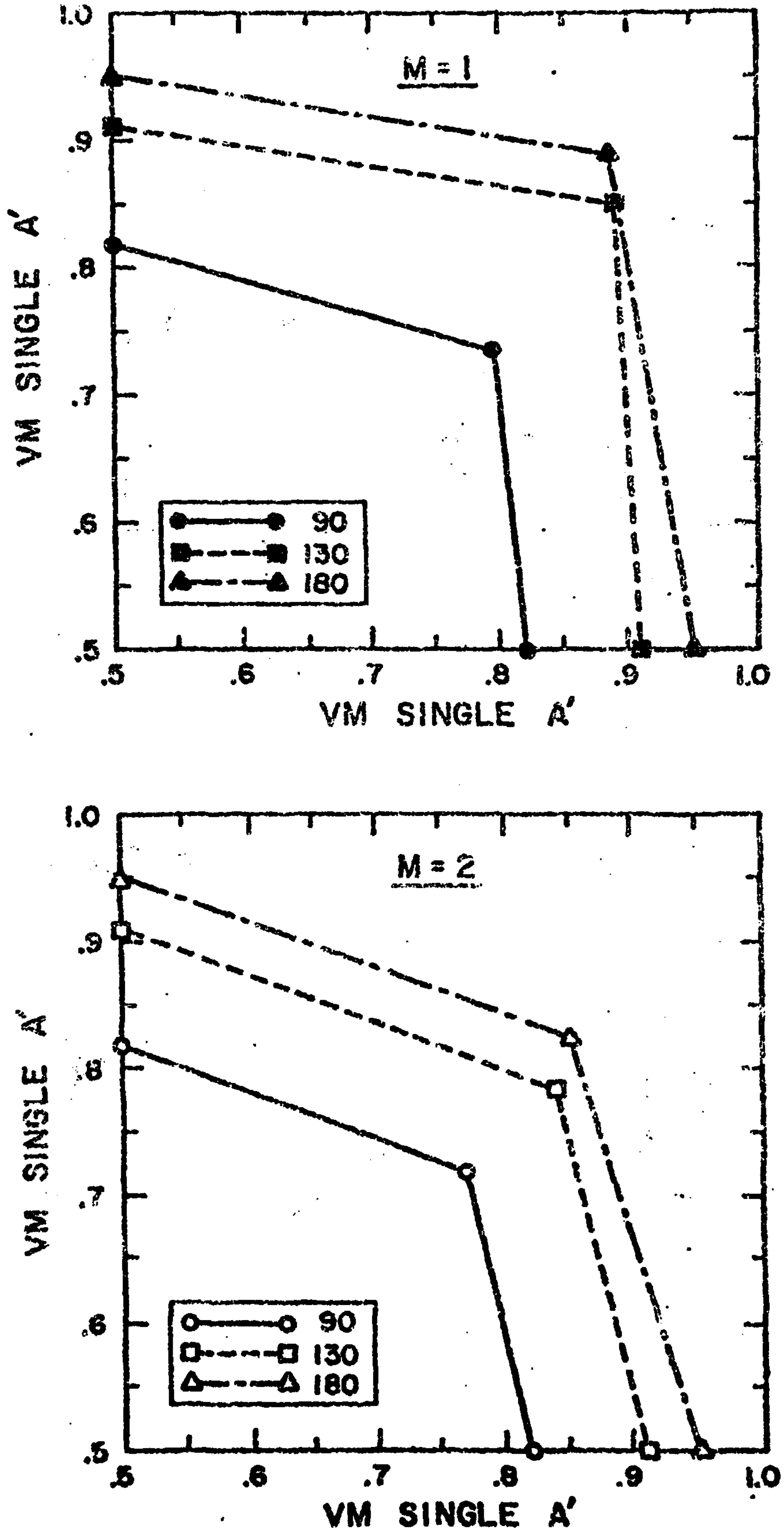

Figure 11. Experiment 10 A' POC curves for Experiment 10 dual control processing search sessions 2-5.

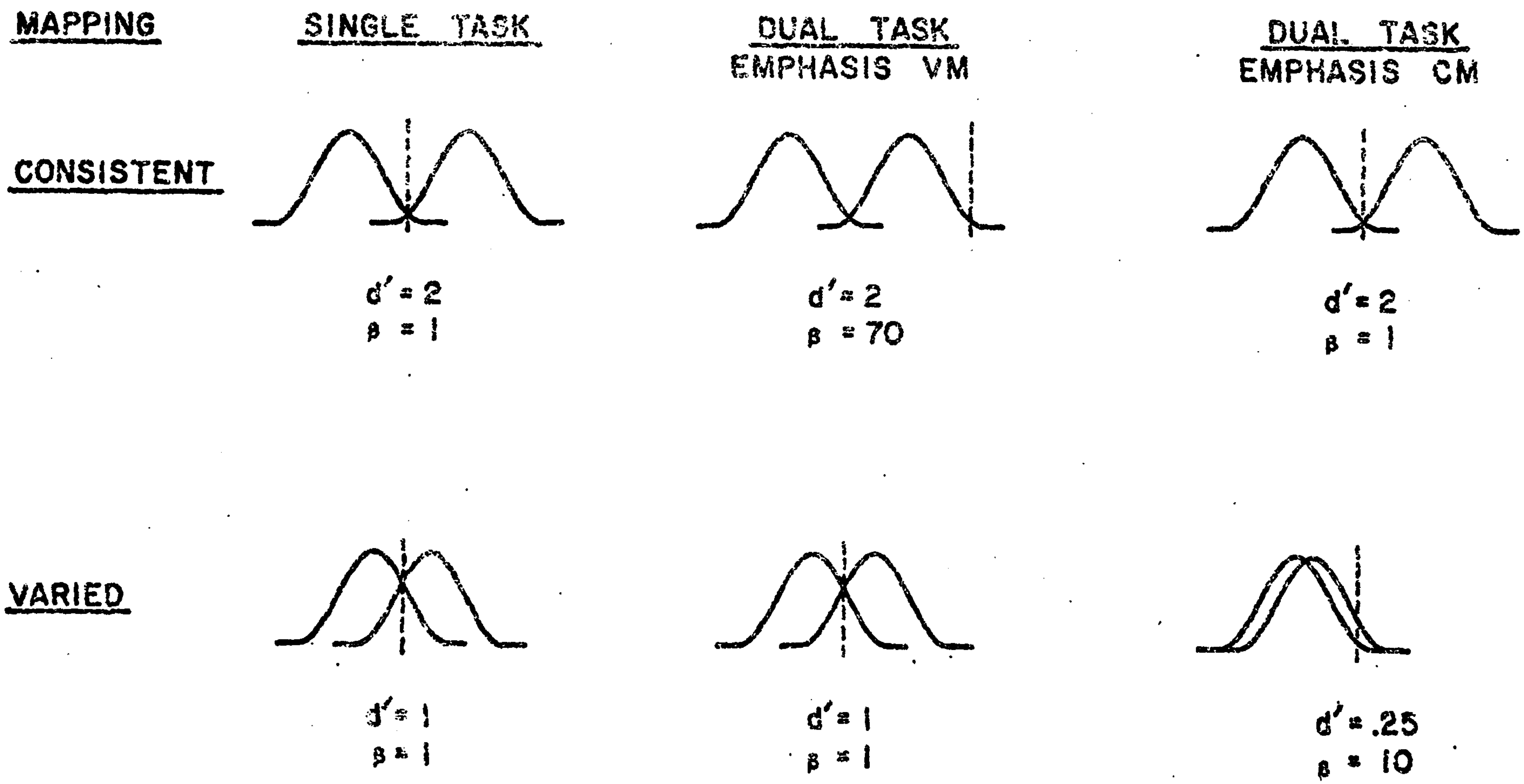

Figure 12. Interpretation of noise and signal distribution for single and dual task conditions.

dual task controlled processing performance at the single task level. In order to maintain dual task VM performance, all CM performance feedback was eliminated, subjects were told to place all of their emphasis on the VM task, and the experimenter reprimanded the subject whenever VM dual performance was not equal to VM single performance. These procedures were necessitated because subjects tended to utilize controlled processing resources on the non-emphasized VM diagonal. Since the automatic processing detection is not resource sensitive, one can conclude that subjects have a tendency to waste controlled processing resources on an automatic processing task.

Experiment 7 showed that process-specific target probabilty influenced VM detection rate. This suggests that the process-specific target probability must be matched between single and dual task conditions. For example, if the single task target probability is .25, when combined with a secondary detection task, the task-specific target probability should be mainained at .25 (e.g., VMS=.25, CMS=.25, VMD=.25, CMD=.25, even though the single task target probabilty is .25, and the dual task target probability is .5). If task-specific target probabilities are not controlled for, dual task performance interpretations can be confounded.

Even after extensive training, joint controlled processing with controlled processing can not be done without deficit. After extensive controlled processing practice, combining two similar controlled processing tasks resulted in a severe sensitivity deficit. After extensive training, combining an automatic and controlled process did not result in an automatic or controlled process sensitivity deficit.

The present conclusions are based on results from a target detection paradigm. The present experiments tested a particular type of automatic processing referred to as the automatic attention response (see Shiffrin and Schneider, 1977). Hence, one must be cautious in extrapolating the present results to all automatic and controlled processing tasks. The clear demonstrations of complex dual automatic and control processing tasks (e.g., shadowing a verbal message while playing a piano, Alport, Atonis, and Reynolds, 1972), do suggest that the present results can be extrapolated to dual automatic and controlled processing situations.

Between Process Dual Task Implications

The automatic/controlled processing framework predicts that costless automatic processes exist. The undifferentiated resource pool hypothesis (Kahneman, 1973, Navon and Gopher, 1979), or the multiple resource pool hypothesis (Wickens, 1980) predict dual task decrements whenever the total resources demanded in the dual task situation are greater than the total available resources. Frequently complex tasks do not show dual task tradeoffs (see above, Ogden, Levine, and Eisner, 1979). The automatic/controlled processing framework suggests that automatic processes can be effectively cost free. Whether automatic processes are "free" or just "cheap" (Navon and Gopher, 1979) in terms of resource cost, depends on the operational definitions of the words.

It is conceivable that there is a cost to enable an automatic process. Dual between process experiments frequently show an additive effect of performing the dual tasks with no interaction between the difficulty manipulations of the two tasks (see Logan, 1979). This suggests that resources may be required to enable an automatic process, but the execution of the processing itself may not require resources. This enabling cost might best be conceptualized as maintaining a chunk in memory. The cost of maintaining a dual process chunk may be no greater than that of maintaining a chunk enabling a single process. This is similar to the approximately equal cost of maintaining a word versus a letter in short term store (Miller, 1956). The apparent costless nature of automatic processing in the present experiment may be due to: a) automatic search itself requires no resources, and b) there is no differential cost in maintaining a single versus a dual process enabling chunk. The hypothesis that automatic enabling conditions can be chunked suggests that some task specific time sharing training may be necessary to enable costless automatic and control process performance. This is consistent with the somewhat reduced dual task performance we have seen in the first session of practice with new conditions (Experiments 2, 4, 5, 7, and 8). The hypothesis also agrees with the benefit of task specific time sharing training (Spelke et al, 1976; Logan, 1979; Hirst et al, 1980).

The present experiments have illustrated that the additional automatic processing can occur with no measurable deterioration in simultaneous control processing. This occurred in conditions where control processing was still clearly resource sensitive and not at ceiling.

The presence of large criterion shifts suggests between process dual task methodology must be careful to separate sensitivity from criterion shifts. In Experiment 8 the automatic processing criterion shifted from a beta of 1.7 to 71.2 in the single and dual task conditions, respectively. The presence of such large criterion shifts can confound measures which do not explicitly separate the criterion of each of the tasks. For example, in Experiments 1 through 4, it was inappropriate to assume that the false alarm for the automatic and controlled processing tasks in the dual task conditions were equivalent. This inappropriate assumption resulted in an underestimate of the automatic processing sensitivity. The potential for criterion shifts in automatic processes makes interpretations of complex dual task procedures difficult. For example, in tracking, a more conservative tracker seems equally sensitive to tracking error, but has a higher criterion as to the size of the corrective movement, thus resulting in a reduction of gain of tracking error (Wickens, 1976).

Since subjects have a tendency to waste controlled processing resources on automatic processing tasks, between process dual automatic/control task experiments must emphasize the controlled process task. When subjects allocated limited controlled processing resources to an automatic processing task, the controlled processing task performance deteriorates, and the automatic processing task performance (sensitivity) is unaffected. Hence the instructions and feedback must emphasize to subjects that they must not waste limited controlled processing resources on the automatic processing task. For training operators for dual task performance in real world environments, operators must be convinced not to waste controlled processing resources on tasks which are

already automatic.

Within Process Dual Task Implications

The automatic/controlled processing framework suggests that controlled processing can develop an automatic processing stage, and then limited controlled processing resources can be allocated to higher level stages. Controlled processing can be interpreted as "training wheels" for the development of automatic processing (see Schneider and Shiffrin, 1977b, pg. 148-151). Limited controlled processing resources are utilized to develop cost free automatic processes. In reading for example, after sufficient training word encoding would become automatic and hence not require limited controlled processing resources. With automatic word encoding, limited controlled processing resources could be utilized to modify semantic memory with the results of the automatically encoded words. Substantial "overtraining" would be necessary to make the word encoding processes automatic. After sufficient training, word encoding is equivalent, or sometimes superior, to letter encoding (see Estes, 1977).

The observed tendency of subjects to waste limited controlled processing resources on an automatic processing task would inhibit subjects developing complex processing capabilities. Even after subjects have developed automatic word encoding capabilities, poor readers may often waste valuable controlled processing resources on the word encoding task. Laberge and Samuels (1974) report that for beginning readers to increase chunking, the demand for accuracy may have to be relaxed. In the present experiments subjects were pressured to completely ignore automatic processing performance in order to keep from wasting controlled processing resources on the automatic processing task. Since controlled processing is necessary for the development of automatic processing, and might be slightly more accurate than automatic processing in some situations, it is not surprising that subjects have a tendency to continue to allocate controlled processing to an automatic processing task. In complex within process dual task situations, subjects have to be encouraged to de-allocate control processes from already developed automatic processes, and to allocate the control processing to higher levels.

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Footnotes

[1] The following sentence illustrates the difficulty of reading inverted text.

This is the time for all good men to come to the aid of their country.

[2] There are at least two important disagreements. The first is the importance of consistency and the second is that if modification of memory is a control process function (which was suggested in Shiffrin and Schneider, 1977, pg. 160-162), multiple memory modification tasks should interact. These issues are too lengthy to be discussed in the present paper.

[3] A series of pilot studies were carried out to select a set of equally confusable letters. We started selecting a set of letters from Townsend (1971) confusion matrices and added and deleted specific letters until we had the best equally confusable set of seven disimilar letters for our font. Note, since letter similarity has a major effect on the development rate of an automatic process, proper letter selection and counter balancing of letter effects are important for clear CM/VM differences.

[4] Since the probability of a joint CM and VM false alarm was very small (average .005), treating false alarms as correct rejections of the other dual task condition could have biased the correct rejection rate upward only slightly (assuming independence of false alarms). Removing this potential bias would not have changed the interpretation of any of the results.

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